AD-A147 092 CONTAMINATION AND DISTORTION OF STEADY FLOW FIELD INDUCED BY DISCRETE FRE..(U) TENNESSEE UNIV SPACE INST TULLAHOMA DEPT OF AEROSPACE AND MEC.. M KUROSAKA 1/1

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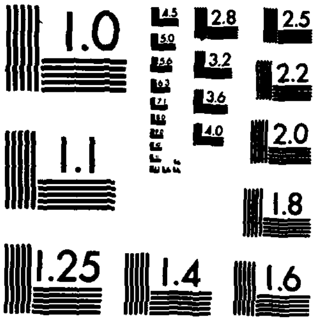
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REPORT DOCUMENTATION PAGE

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17. COSATI CODES			18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)	
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			UNSTEADY FLOW	ENERGY SEPARATION IN FLOW
			KARMAN VORTEX STREET	ORGANIZED REYNOLDS STRESSES

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

This annual technical report covers the first year, Phase I activity of a research program initiated in January 1, 1983. The main objective of the present program is to investigate the influence of Reynolds stresses of organized origin - induced by discrete frequency disturbances - in deforming and affecting the steady internal flow of aircraft engines. In particular, attention of the present research is focused upon the effect of orderly disturbances such as (A) the "vortex whistle" upon the Ranque-Hilsch effects and (B) Karman vortex street in causing temperature separation within the wake. With regard to (A), as a continuation of preceeding program F49620-78-C-0045, the measurements taken in the upscale test rig reconfirmed that the vortex whistle is largely the cause of total temperature separation in swirling flow, or the Ranque-Hilsch effect; in addition, a new phenomenon, appeared to be related to another thermoacoustic effect, has been observed. On the temperature separation induced by Karman vortex street, a specially designed anechoic wind tunnel has been designed and constructed with an objective to intensify the strength of Karman vortex by acoustic resonance within the wind tunnel. The checkout of the tunnel has been

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completed and necessary modification has been implemented in the test rig. The preliminary results indeed show the presence of intense resonance at the predicted conditions.

2. Research Objectives

The main objective of the present program is to investigate the influence of Reynolds stresses of organized origin – induced by discrete frequency disturbance in deforming and affecting the steady internal flow such as the one in turbomachinery. Specific objectives are twofold:

Task (A).

To complete the investigation of the Ranque-Hilsch effect conducted under AFOSR Contract F49620-78-C-0045.

Task (B).

To investigate the effect of Kármán vortex street on causing thermal separation in the wake of bodies.

3. State of Research

Task (A).

Using an upcale vortex tube test rig described in Ref. 1, measurements of internal flow have been continue.

Figure 1 shows the layout of the upscale test rig; the exploded view of this is shown in Figure 2, its photo in Figure 3. Except for its enlarged size (for instance, the main pipe is 2 inches in diameter and 4.78 inches in length), the design is essentially the same as that of the small test rig, described in Reference 2.

In this rig, it was found that, by placing at the exhaust a ring with an opening smaller than that of the main pipe (shown in Figure 1 as a darkened line), the vortex whistle can be suppressed. For the ring opening equal to 0.4" in diameter, Figure 4 displays (a) the frequency spectrum (b) the radial distribution of tangential velocity, V (c) the radial distribution of total temperature separation $\Delta T^* = T^* - T^*_{in}$ (T^* : total temperature, T^*_{in} : inlet total temperature) and (d) entropy increase $\Delta S = S - S_{in}$ (S_{in} : inlet entropy). Note that in the absence of the vortex whistle the tangential velocity distribution is clearly a Rankine vortex (or a Burger vortex); total temperature

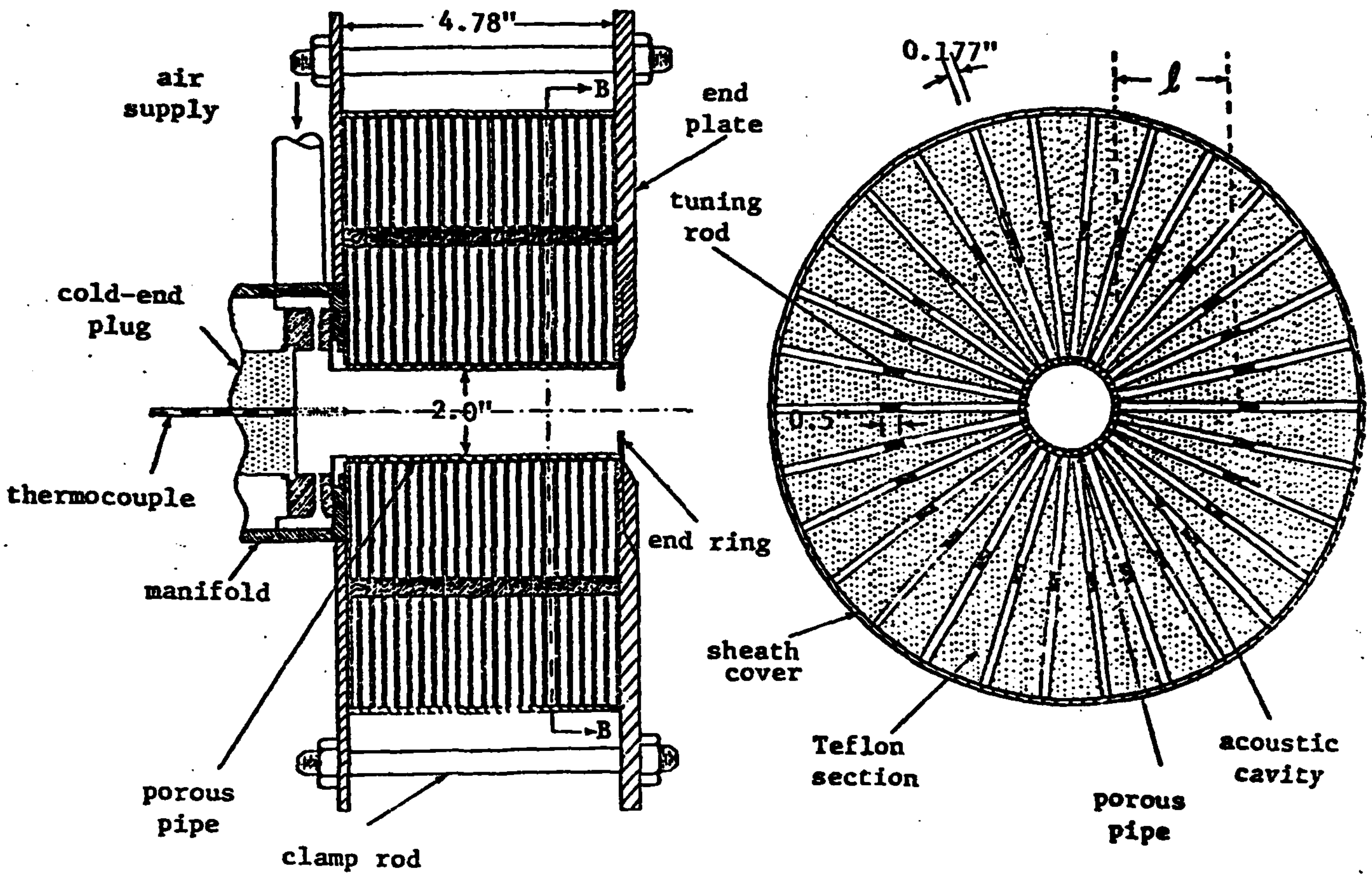


Figure 1. Layout of upscale swirl flow test rig.

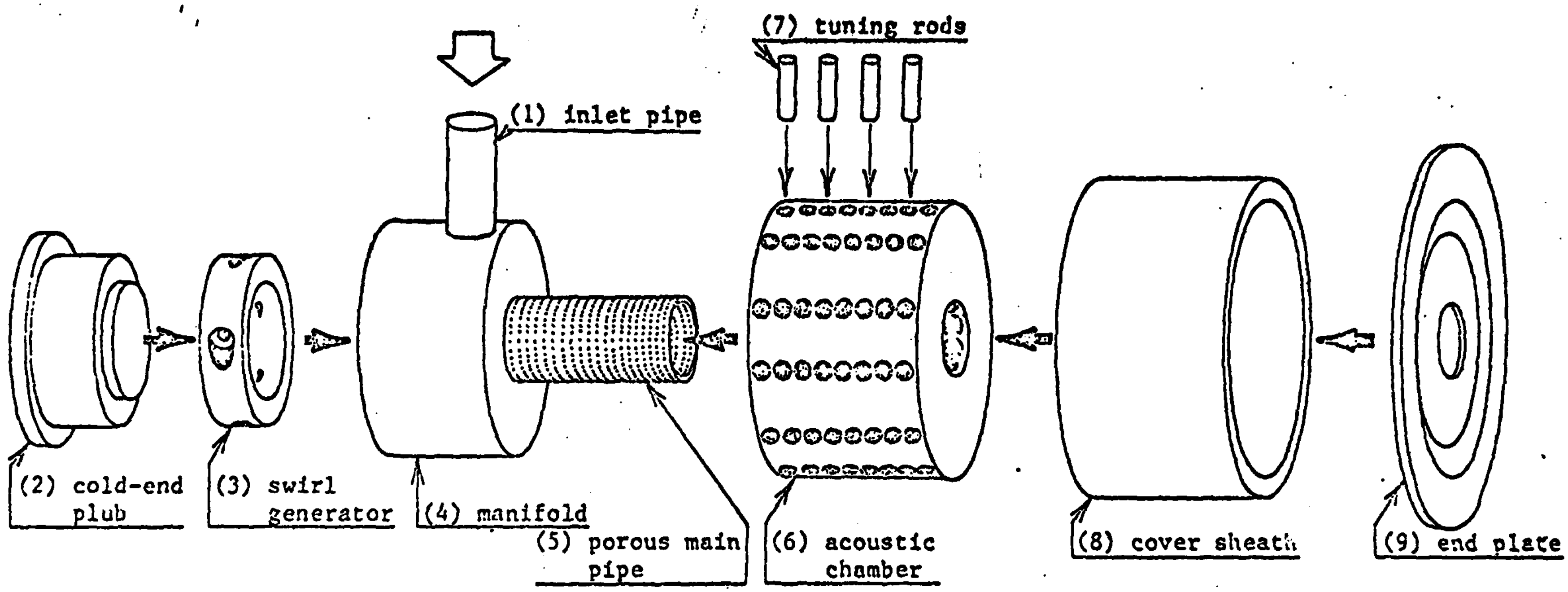


Figure 2. Exploded view of vortex-flow test rig.

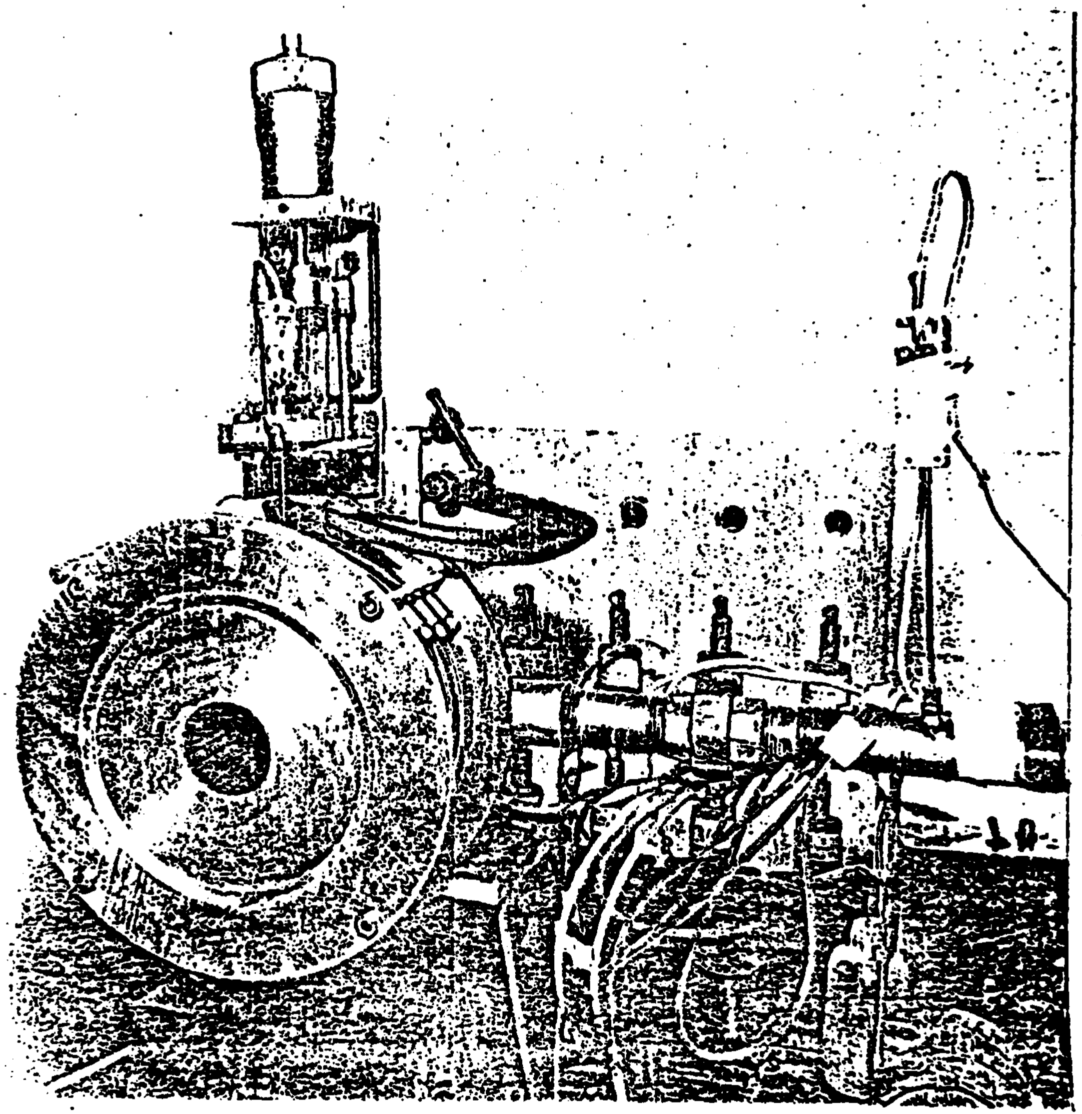


Figure 3.. Photo of upscale swirl flow test rig.

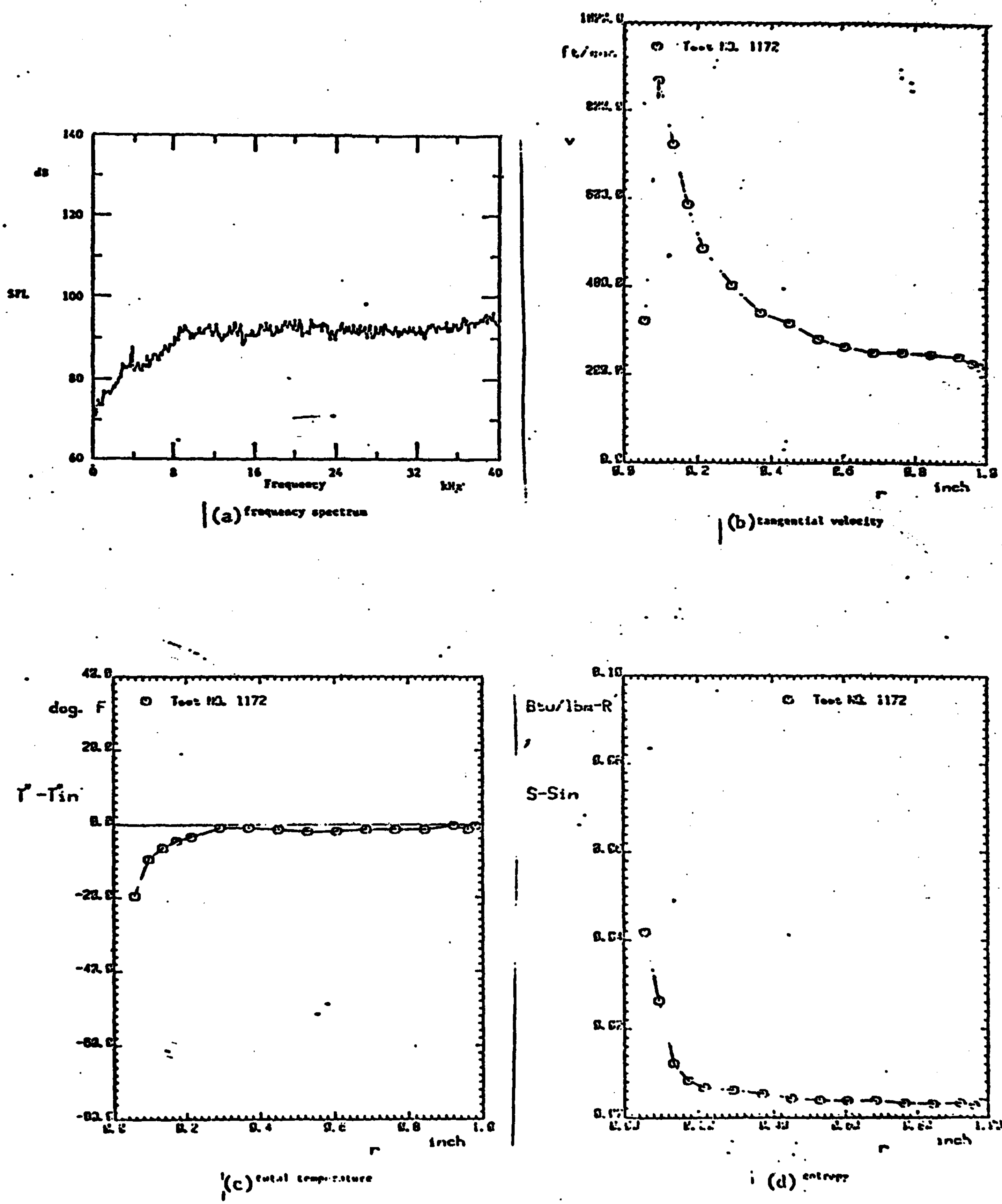


Figure 4. Radial profile with exhaust ring having an opening of 0.4" in diameter; inlet pressure = 60.52psia.

is practically uniform except near the core region where it shows a dip due to the viscous stressess, as evidenced by the local increase in entropy.

Compare these with Figure 5 corresponding to the situation where the ring at the exhaust is removed. Note that due to the presence of the dominant peaks of the vortex whistle in the frequency spectrum, the tangential velocity distribution changes to a forced vortex type, except for those region within the boundary layer on the wall; the total temperature continuously decreases toward the centerline and the overall temperature separation becomes larger, in spite of the difference in inlet pressures; Figure 4 corresponds to the inlet pressure of 60.52psia; Figure 5 to 29.90psia. All these are consistent with the analytical prediction of Ref. 2.

Figure 6 shows the effect of sound suppression, corresponding to the acoustic cavity length of 1 3/8 inch. (a) and (b) show the changes in the frequency spectrum caused by the sound suppression when the frequency of the vortex whistle hit the tuned frequency of 1.2 kHz; (a) just before the sound suppression corresponding to the inlet pressure of 46.09psia; (b) just after the sound suppression corresponding to the inlet pressure of 46.92psia. The sudden decrease in the sound intensity is obvious. The changes in the radial profile of total temperature is shown in Figure 6 (c); at the moment of sound suppression, the temperature near the centerline suddently leapt upward (this is the same as that of the small test rig) while the temperature near the tube periphery took a plunge; this rise and fall is what is to be expected from the heat balance.

All these fit well with what have been anticipated. However, one unexpected happened in the tangential velocity distribution; as Figure 6 (d) shows, the forced vortex formed by the presence of the vortex whistle did not revert to a Rankine vortex after its suppression; instead, the swirl became smaller near the center, contrary to the expected increase there. Various measurements using different probes taken under different conditions always reproduced this anomalous profile after the sound suppression.

A clue why the expected Rankine vortex fails to emerge after

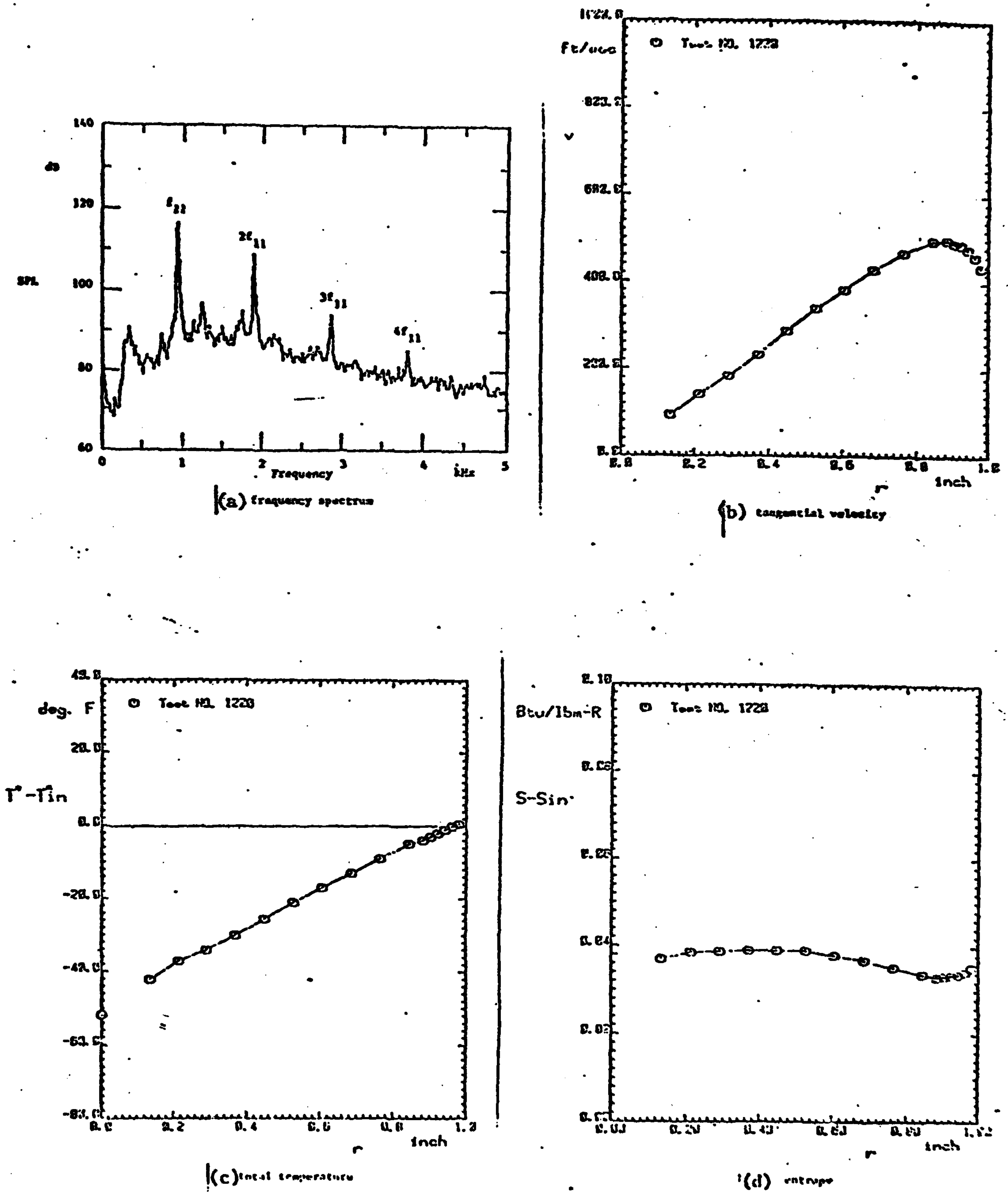
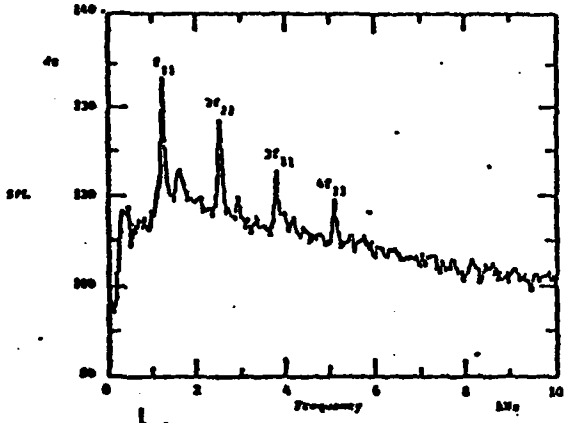
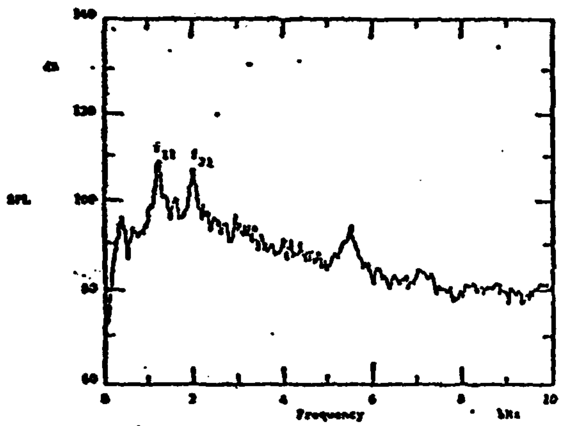


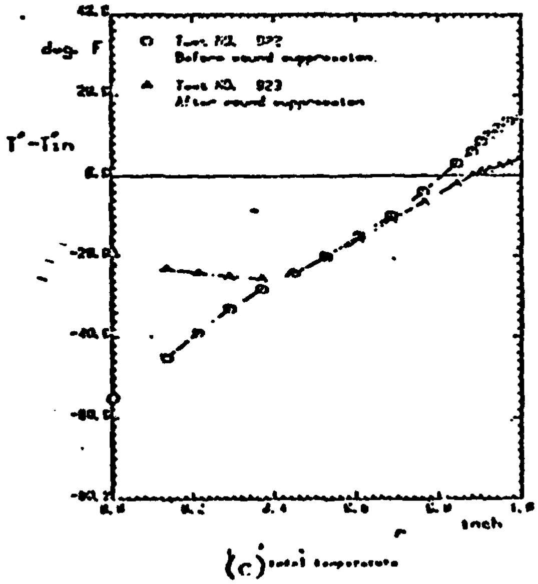
Figure 5. Radial profile without exhaust ring;
Inlet pressure = 29.90psia.



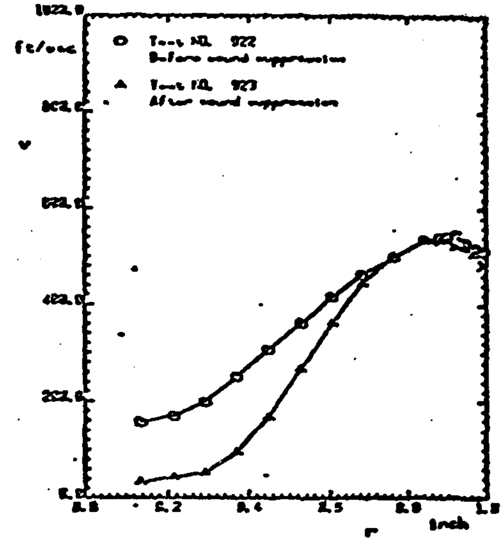
(a) frequency spectrum before sound suppression



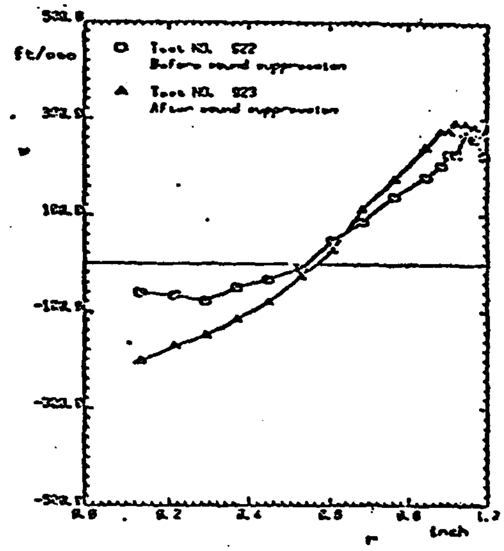
(b) frequency spectrum after sound suppression



(c) radial temperature



(d) tangential velocity



(e) axial velocity

Figure 6. Changes in radial profiles due to sound suppression.

the sound suppression is found in the change in the axial velocity distribution, Figure 6 (e). Before the sound suppression, there exists a region of reversed flow near the centerline and this backflow is caused by the reduced pressure at the core of the vortex; note that after the sound suppression, the velocity of the backflow increases by about three times. We do not as yet know the exact reason why the backflow becomes increased but it is easy to understand why this increase in the entrainment of the ambient air affects the tangential velocity in the core. Since the ambient air does not possess any swirl, its entrainment into the vortex core tends to reduce the tangential velocity; thus the increased entrainment after the sound suppression prevents a Rankine vortex from emerging.

In order to substantiate such an influential role of entrained ambient air without swirl, we have performed the following test: in the test rig where a ring with a small opening is attached to the exhaust - - as mentioned, Rankine vortex is found to exist in that arrangement, we injected a secondary air without swirl at the exhaust; the secondary air is directed toward upstream in order to simulate the entrainment of ambient air as shown in Figure 7. The effect of this artificial injection upon the tangential velocity distribution is shown in Figure 8; we can see clearly that the high tangential velocity within the core of a Rankine vortex is drastically reduced by the effect of backflow.

Thus it is almost certain that in Figure 6 (d) the increased backflow prevents the formation of Rankine vortex after the sound suppression * Simple means to prevent this backflow-increase such as installation of various entrainment block at the exhaust were found to be not effective. Thus some modification of the test rig itself is

* The presence of the backflow may raise a question whether the observed temperature rise near the centerline of the sound suppression, Figure 6 (c), might be due to entrainment of warm ambient air into sub-zero stream at the centerline. We confirmed that this effect is negligibly small by the following test: by heating the ambient air to 300^o F, we observed the temperature rise at the centerline after the sound suppression; the difference between the results of the heated and room air is only about 2^oF.

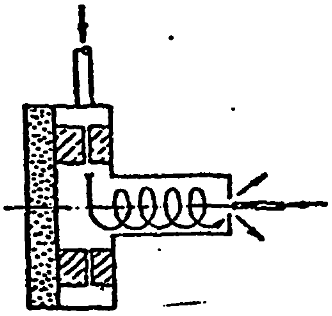


Figure 7. Secondary Air Injection.

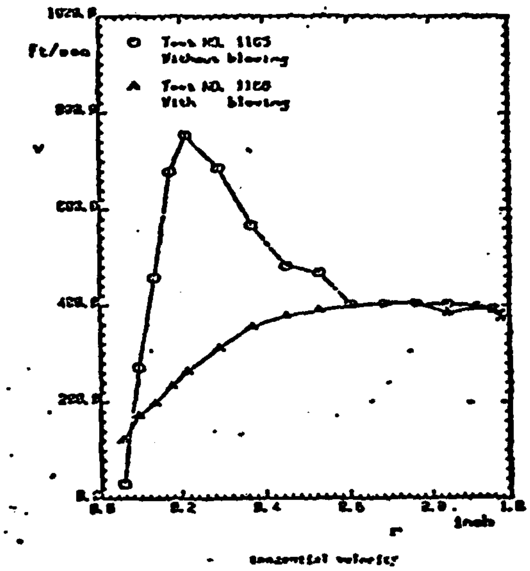


Figure 8. Changes in tangential velocity due to secondary air injection.

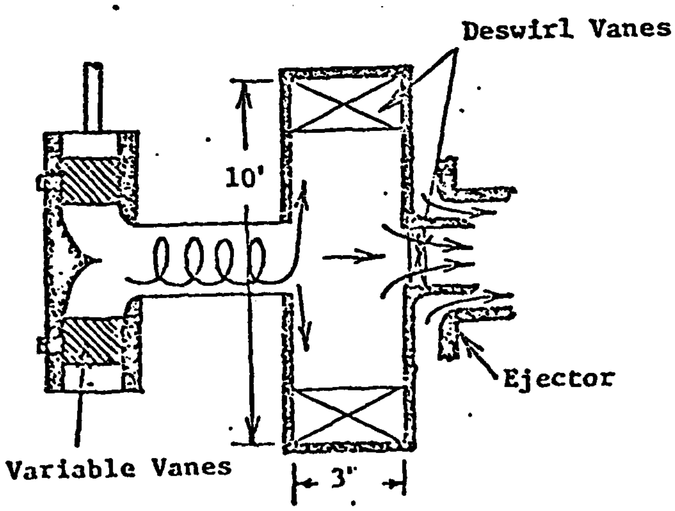


Figure 9. Proposed modification.

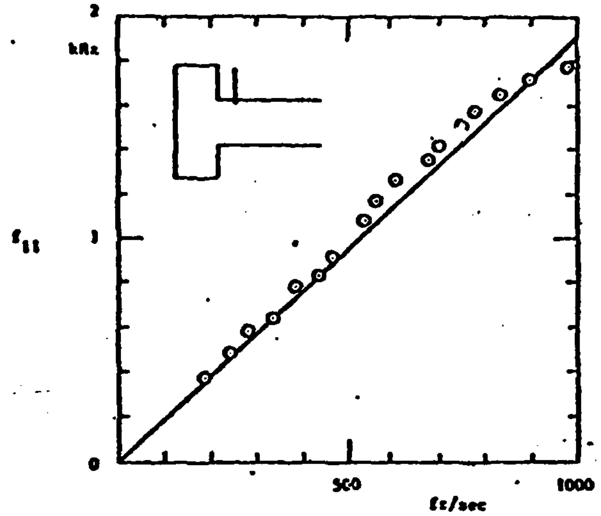
required in order to minimize the contaminating effect of air entrainment.

We feel that the following modification, shown in Figure 9 as dark lines added to the existing test rig, will almost surely eliminate the backflow problem: installation of (a) a centerbody near the swirl generator and (b) partially evacuated chamber at the exhaust. The contoured form of the centerbody will serve to accelerate the flow in the axial direction. The enclosed limited volume of the air within the evacuated chamber and the continuous blowing-off by the ejector will minimize the entrainment of air into the main pipe section; within the chamber, deswirl vanes are provided to prevent the undersirable regeneration of the vortex whistle at the exhaust near the ejector. The installation of the partially evacuated chamber, together with the flow pattern change at the time of the sound suppression, described in Reference 2, would prevent the increase of backflow after the sound suppression.

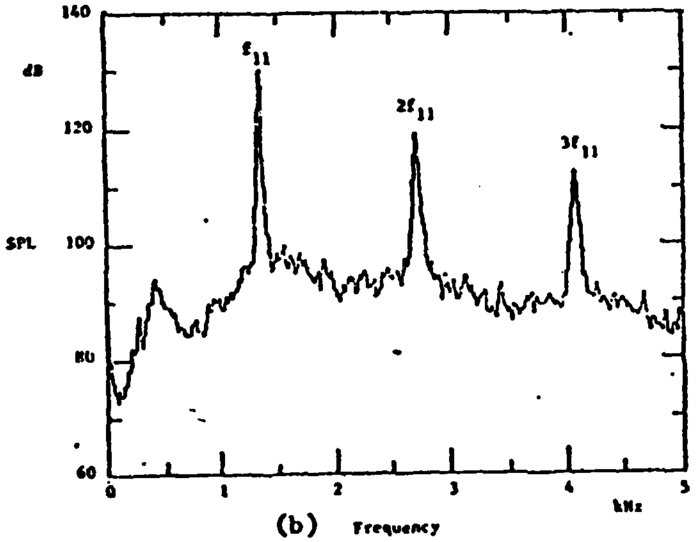
In addition to these modifications, it is desirable to change the swirl generator from the present one with tangentially drilled slots to variable vanes; this enables one to vary the two parameters independently - - the Reynolds number and swirl parameter (the ratio of swirl velocity to velocity).

However, these modifications are rather extensive and cannot be carried out within the scope of the present project without incurring delay to the other tasks; therefore, it has been decided that the modifications will be delegated to a future phase.

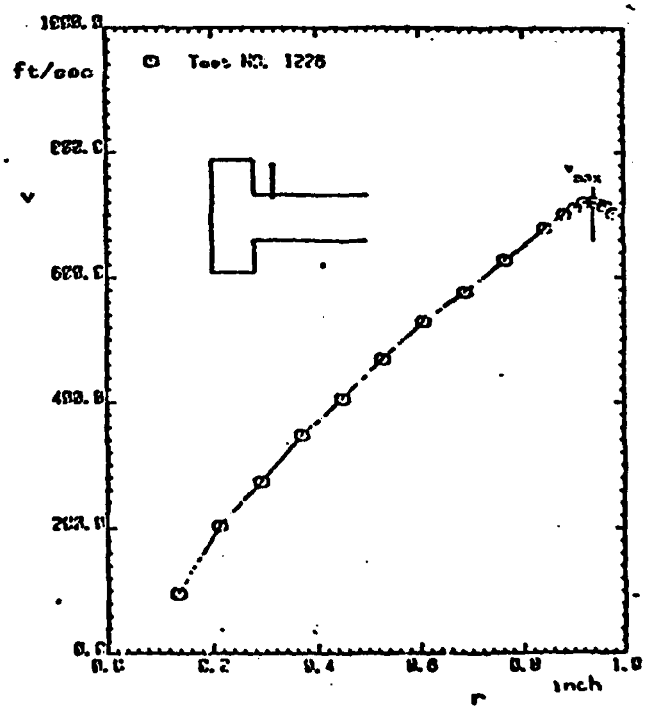
In addition to these results related to the sound suppression, we were able to confirm by direct means that the measured frequency of the vortex whistle agrees well with the predicted value of Reference 2; Figure 10(a) shows this, where f_{11} is the fundamental frequency of the vortex whislte, identified in Figure 10(b) and V_{max} is the tangential velocity at the outer edge of the boundary layer shown in Figure 10(c). The solid line in Figure 10(a) corresponds to the prediction, $f_{11} = \frac{1}{2\pi} V(r = R)/R$, where $V(r = R)$ is the inviscid swirl velocity at the tube periphery, $r = R$.



(a) V_{max}



(b) Frequency



(c)

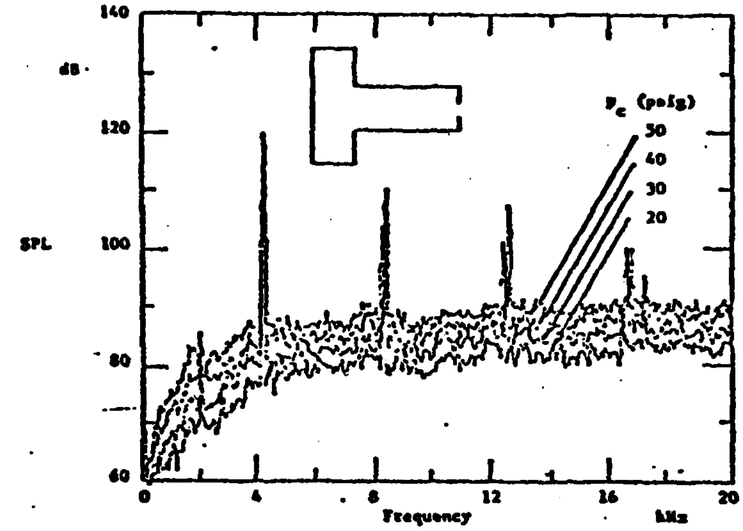
Figure 10. Frequency vs. Tangential Velocity

During the course of the past investigation, we encountered what appears to be a new phenomenon of heating/cooling induced by acoustic streaming. The phenomenon was observed when the main pipe of Figure 1 was replaced with a solid pipe of 2 inch in diameter (the results of Figure 4 corresponds to the porous pipe of the same diameter with acoustic cavity length set to zero); a ring with 0.4 inch opening diameter was placed at the exhaust end of the solid pipe. As the inlet pressure increased above 10 psig, a ringing pure tone emerged; this pure tone was generically different from the vortex whistle, because its frequency remained unchanged when the inlet pressure or swirl was increased. Figure 11 (a), frequency spectra corresponding to different inlet pressure P_c, clearly shows this (Contrary to the solid pipe, the porous pipe with the end constriction did not emit any pure tone, as seen from Figure 4 (a)). At the moment the pure tone emerged, the exhaust end of the solid pipe became noticeably warm and it became intensely hot as the inlet pressure was raised, the manifold end of the solid pipe remained essentially unchanged, Figure 11 (b).

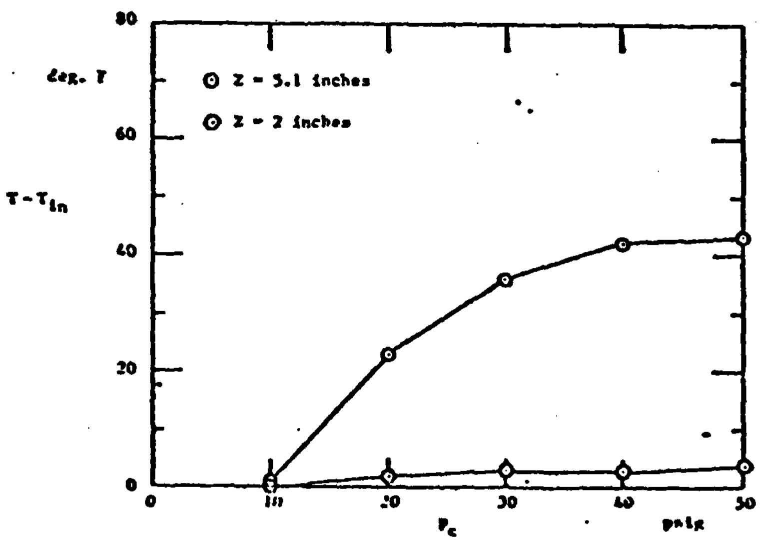
Although no detailed investigation has been carried out, the disturbance appears to be of $e^{i(m\theta-\omega t)}J_m(\frac{\omega}{a}r)$ type: the fundamental peak in Figure 11(a) corresponds to ω, the lowest eigenvalue obtained from the boundary condition $J_2(\frac{\omega}{a}R) - J_0(\frac{\omega}{a}R) = 0$, where a is the acoustic speed and R the pipe radius; $|m| = 1$. If indeed so, this phenomenon, though reminiscent of Hartmann - Sprenger tube (Hartmann, Ref 3; Sprenger, Ref 4) may not be the same; not only the Hartmann - Sprenger tube does not require swirling flow but it is related to resonant oscillation in the axial direction (Merkli and Thomann, Ref. 4). Thus the phenomenon appears to be worthy of detailed, separate investigation.

Task B

Here the objective is to examine the effect of Kármán vortex street upon the steady flow field. For this, a test rig has been designed and manufactured. As shown in Figure 12(a), the test section is rectangular, 6" x 6" in its size; a cylinder or airfoil may be placed trasvesely to the direction of air. Compressed air stored in a separate tank first enters a settling tank of 20 inches in diameter and 10 ft.



(a) frequency spectra



(b) temperature

Figure 11. A new phenomenon of temperature separation induced by different acoustic streaming.

in length; three wire mesh screens are placed within the tank in order to stabilize the flow. The air enters the test section via a transition piece. Close to the transition piece, 5 inches downstream of it, the test cylinder or airfoil may be located, so that the velocity distribution at the test section becomes a uniform, free from the effect of the wall boundary layer. Two optical glass windows are placed on the sides of the test section; by them, the test cylinder or airfoil may be supported. Two test cylinders, one with 1 inch in diameter and the other in 1/2 inch diameter, have been chosen; the tunnel resonant Mach number (M_r) for the former corresponds to about 0.37, while M_r for the latter about 0.22. Both are instrumented with thermocouples, embedded on thier surfaces, and installed with static pressure taps ; they are located at the middle of the cylinder. Since the test cylinders have to be made of thermally insulated material, they are made of Delrin.

The shake-down and checkout of the test rig have been completed. They show that both the velocity and temperature profiles are uniform at the test section, the boundary layer thickness being less than 0.2". Background noise was initially found to be high but it was subsquently lowered by the installation of acoustic foams lined on the inner wall of the settling tank; the interior of acoustic foams serves also a diffuser. By this provision, the sound levels are less than 100db even at the Mach number of 0.5, except for a low frequency peak at 150 Hz.

The preliminary test with cylinders placed within the test section indeed confirmed the presence of intense acoustic resonance at the Mach number predicted.

Presently, the measurements for the recovery temperature on and off the cylinder surface are being made.

Reference

1. Kurosaka, M., Goodman, J. R., Kuroda, H. and Chu, J. Q. "An Interplay Between Acoustic Waves and Steady Vortical Flow" AIAA Paper 83-0740, presented at AIAA 8th Aerocoustics Conference, April, 1983.

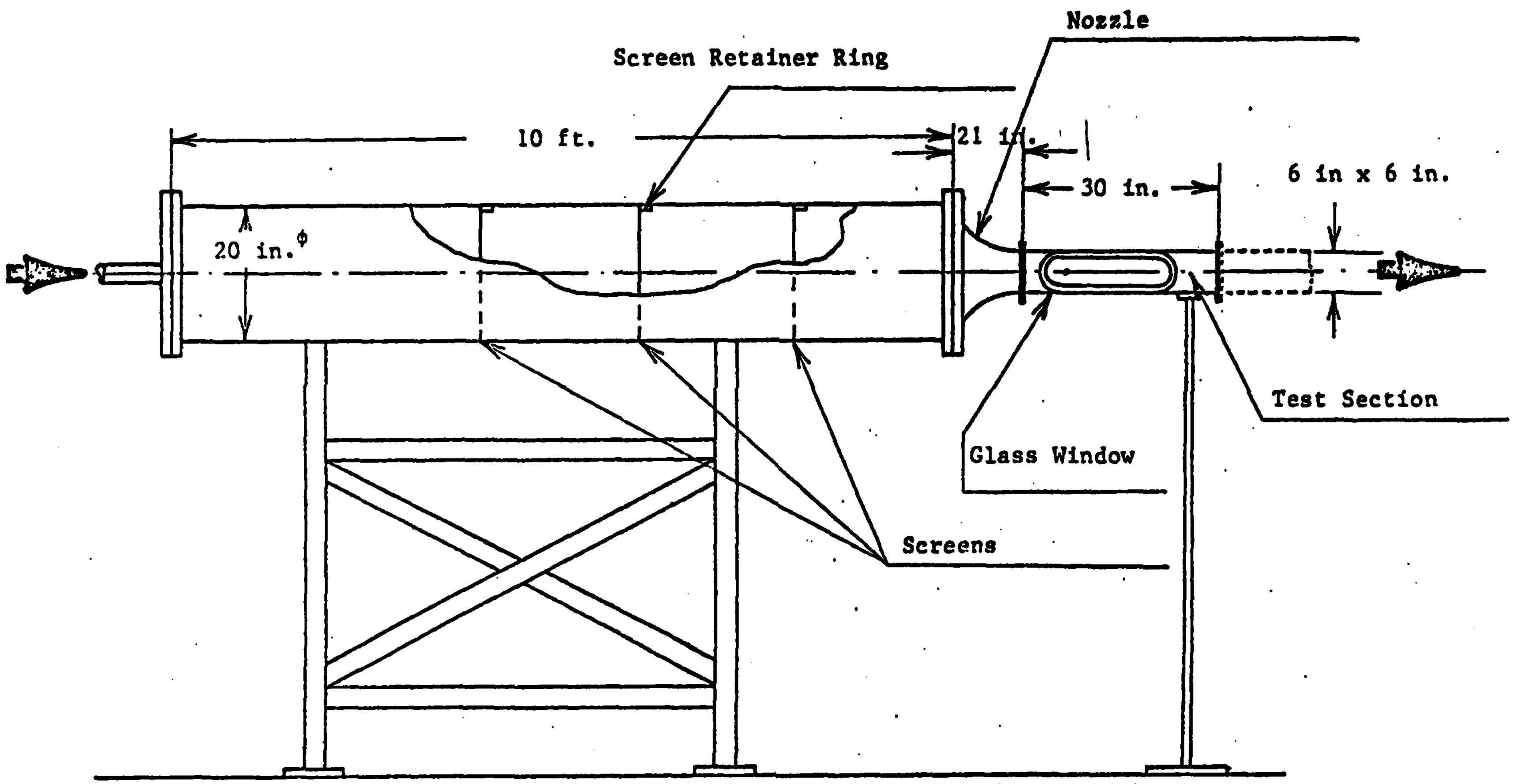


Figure 12. Kármán Vortex Street Test Rig

2. Kurosaka, M., "Acoustic Streaming in Swirling Flow and the Ranque-Hilsch Effect," Journal of Fluid Mechanics, Vol. 124, pp, 139-172, 1982.

3. Hartmann, J., "On the Production of Acoustic Waves by Means of an Air-Jet of a Velocity Exceeding That ofSound", Philosophical Magazine, 1931, pp. 926-948.

4. Sprenger, H., "Über Thermishe Effeckte in Rosonanzrohren" Mitteilungen ans dem Institut für Aerodynamik, 1954, Nr. 21, ETH,Zurich.

5. Merkli, P. and Thomann, H., "Thermoacoustic Effects in a Resonance Tube", Journal of Fluid Mehcanics, 1975, Vol. 70, pp. 161-177.

4. Chronological List of Publications and Awards

The papers published in one year period covered in the present report are as follows:

- "An Interplay Between Acoustic Waves and Steady Vortical Flow" AIAA Paper No. 83-0740, AIAA 8th Aerocoustic Conference, April 11-13, 1983, Atlanta, Georgia

- "The Ranque-Hilsch Effect" in 'Physics News in 1983', ed. P. F. Schewe, American Institute of Physics, November, 1983.; also 'Physics Today', January, 1984 S. 34-35.

In May, 1983, M. Kurosaka received 1983 AIAA General H. H. (Hap) Arnold Award from AIAA Tennessee Section for "proposing and verfiying a radically new theoretical explanation of the Ranque-Hilsch (vortex tube) effect."

5. List of Professional Personnel Associated with the Research

The recipient of advanced degrees awarded in connection with the present grant is as follows:

- H. Kuroda, Ph.D. in Engineering Science and Mechanics, December, 1983

- "An Experimental Study of Temperature Separation in Swirling Flow"

The following additional personnel have been involved in the research:

- M. Kurosaka, Professor of Aerospace and Mechanical Engineering
- W. Riner, as student and an MS Degree candidate
- J. R. Goodman, senior engineer
- R. D. Fizer, senior technician

6. Interactions

The following seminars have been given on the subject:

- "Acoustic Streaming in Swirling Flow and the Ranque-Hilsch Effect" given to the faculty and students at the California Institute of Technology, January 18, 1983; at Yale University, April 6, 1983; at the Air Force Institute of Technology, October 11, 1983; to the staff of United Technologies Research Center, April 7, 1983.

- "Thermocoustic Effects observed in Ranque-Hilsch Tubes" invited presentation at workshop on Natural Engines, Los Alamos National Laboratory, August 8, 1983.

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